NAVIGATING MARS GLOBAL SURVEYOR THROUGH THE MARTIAN ATMOSPHERE: AEROBRAKING 2

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The Mars Global Surveyor (MGS) spacecraft was successfully inserted into an elliptical orbit around Mars on 9/12/97, 01:53:49 UTC. This orbit was near polar (inclination=93.26 deg) with an orbital period of 44.993 hours and apoapsis and periapsis altitudes of 54,025.9 km and 262.9 km respectively.

After 201 orbits and 196 days after Mars orbit insertion, the first phase of aerobraking (AB), called AB1, has ended; after the AB1 termination maneuver, the orbital period was 11.64 hours with apoapsis and periapsis altitudes of 17,870.3 and 170.7 km respectively (Refs. 1,2). Thereafter, MGS was in a science phasing orbit (SPO) and acquired data from the science instruments from 3/28/98 to 9/22/98 (orbits 202 through 572). The second phase of aerobraking (AB2) began on 9/23/98 with the first descent into the atmosphere on P574 and ended with the aerobraking termination maneuver (ABX) on 2/4/99 on A1284. Just prior to ABX, the apoapsis and periapsis altitudes were 456.5 km and 116.7 km respectively with an orbit period of 1.973 hours, a local mean solar time (LMST) at the descending node of 2 hours, 3.6 minutes and an inclination of 92.9 degrees.

AB was responsible for circularization of the MGS orbit. However, two additional orbital conditions had to be satisfied simultaneously. These were a) complete AB2 when the LMST at the descending node was close to 2:00 am and b) the inclination was at 93.0 degrees. This paper describes the navigation of MGS throughout AB2; a companion paper (Ref. 3) describes the strategy and plan for aerobraking. Navigation challenges involved a) the estimation of an atmospheric density model for every drag pass or periapsis-passage by analyzing doppler tracking data, b) the generation of a short-term, that is over one to several orbits, accurate atmospheric density predictions, c) maintaining the spacecraft's orbit within upper and lower bounds of atmospheric density or dynamic pressure during each periapsis-passage, and d) the prediction of accurate periapsis-passage times (Tp) over one to fifteen orbits.

The reference, atmospheric density model used for navigation was Mars Global Reference Atmospheric Model (Mars-GRAM or MG; Ref. 4). A critical component of successful navigation was to provide an independent and accurate estimate of atmospheric density per periapsis-passage which was used to update the Mars-GRAM model in real-time. During AB1, a stationary, atmospheric wave phenomenon was discovered (Ref. 5) and applied to density predictions (Ref. 1). This process was successfully continued throughout AB2. The procedure was: a) estimate a density model for each periapsis-passage, b) accumulate these estimates over approximately ten drag passes thereby sampling local densities over the corresponding periapsis-longitudes, c) trend the ratio density(measured)/density(MG prediction) as a function of longitude, d) model this trend as a fourier series, thus producing a density-factor function and e) apply this function to the MG reference density for future orbits thereby producing more accurate density predictions. An example of the results of this process is given in Fig.1. The three curves represent the time evolution of the density-factor function from orbits 914 to 952 to 985. Note that the top-most curve varies by a factor of three when examined over 360 degrees of longitude; this represents a significant change in density over a small number of orbits.

The density estimation and analysis procedure, evaluation of almost 700 atmospheric densities throughout AB2, the variation and accuracy of density predictions, the Tp prediction accuracy and how effectively we terminated AB2 are the basis of this paper and shall be presented in detail. A summary overview of AB2 is given in the following figures:

Fig. 2 Orbit period reduction throughout AB2.
Fig. 3 Period reduction for each periapsis passage.
Fig. 4 Altitudes at periapsis and apoapsis passage. The discontinuties in periapsis-altitudes are due to the execution of a propulsive maneuver at the previous apoapsis in order to keep densities or dynamic pressures within safe and effective limits.
Fig. 5 Atmospheric densities determined throughout AB2 from analysis of doppler tracking data.

REFERENCES

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3. M. D. Johnston et al, "The Strategy for the Second Phase of Aerobraking Mars Global Surveyor," abstract submitted for this conference.

4. C. G. Justus et al, "A Revised Thermosphere for the Mars Global Reference Atmospheric Model (Mars-GRAM Version 3.4)," NASA Technical Memorandum 108513, Marshall Space Flight Center, July, 1996.

5. G. Keating et al, " The Structure of the Upper Atmosphere of Mars: In Situ Accelerometer Measurements from Mars Global Surveyor," Science, Vol 279, pp. 1672-1676, 13 March 1998.

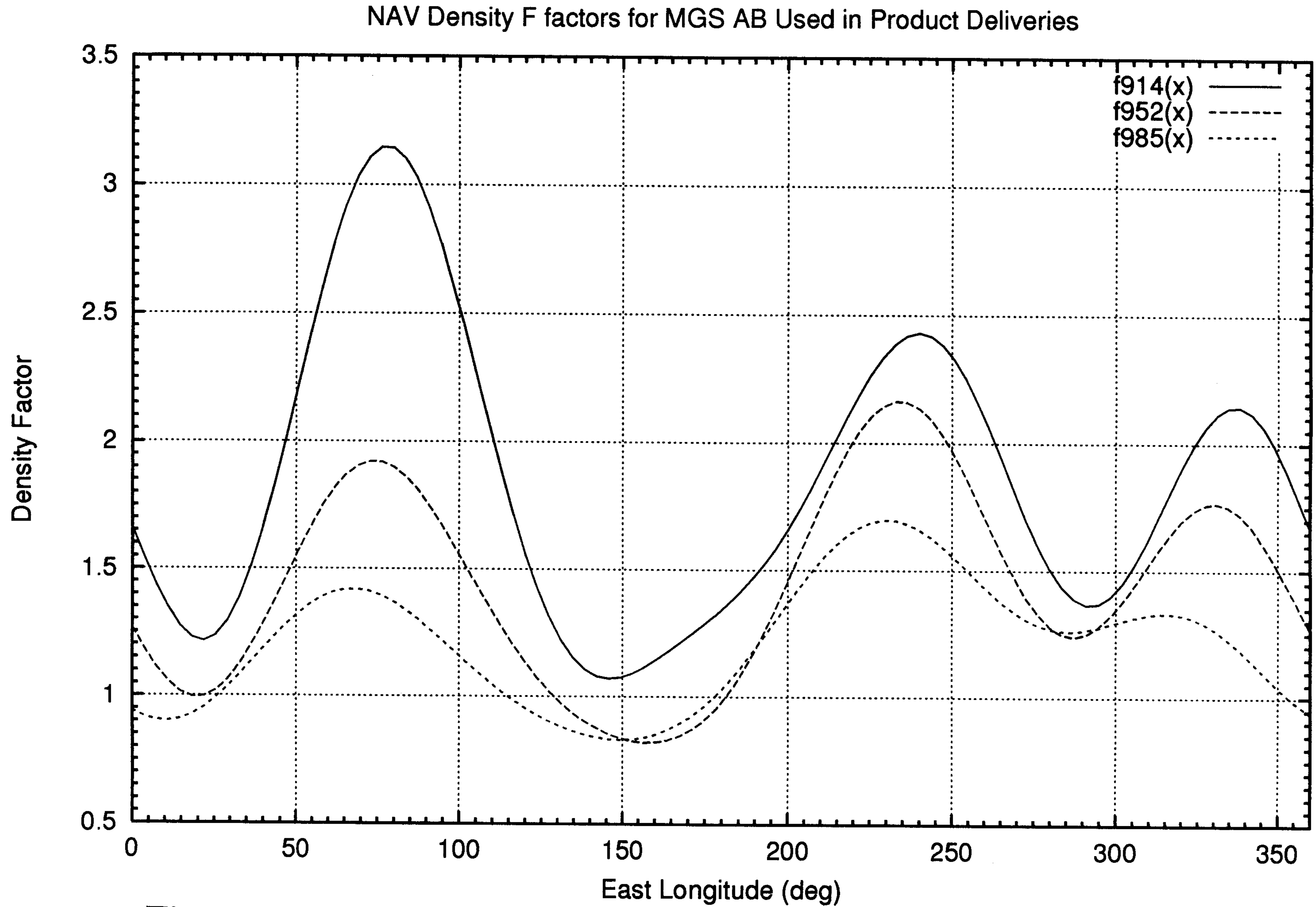
NAV Density F factors for MGS AB Used in Product Deliveries
f914(x)
f952(x)
f985(x)
Density Factor
East Longitude (deg)
3.5
3
2.5
2
1.5
1
0.5
0
50
100
150
200
250
300
350

Figure 1

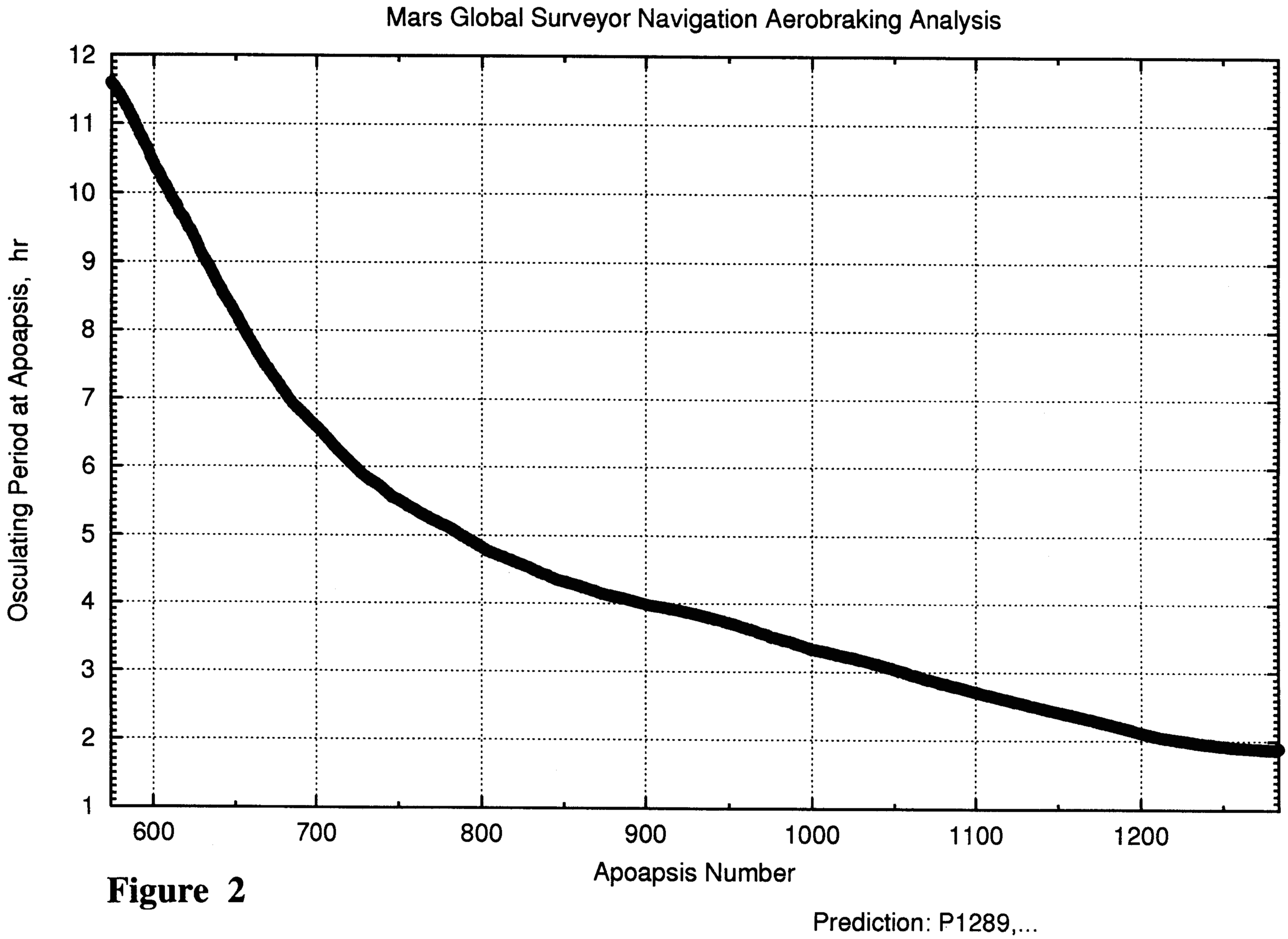
Mars Global Surveyor Navigation Aerobraking Analysis
Osculating Period at Apoapsis, hr
1
2
3
4
5
6
7
8
9
10
11
12
600
700
800
900
1000
1100
1200
Apoapsis Number
Prediction: P1289,...

Figure 2

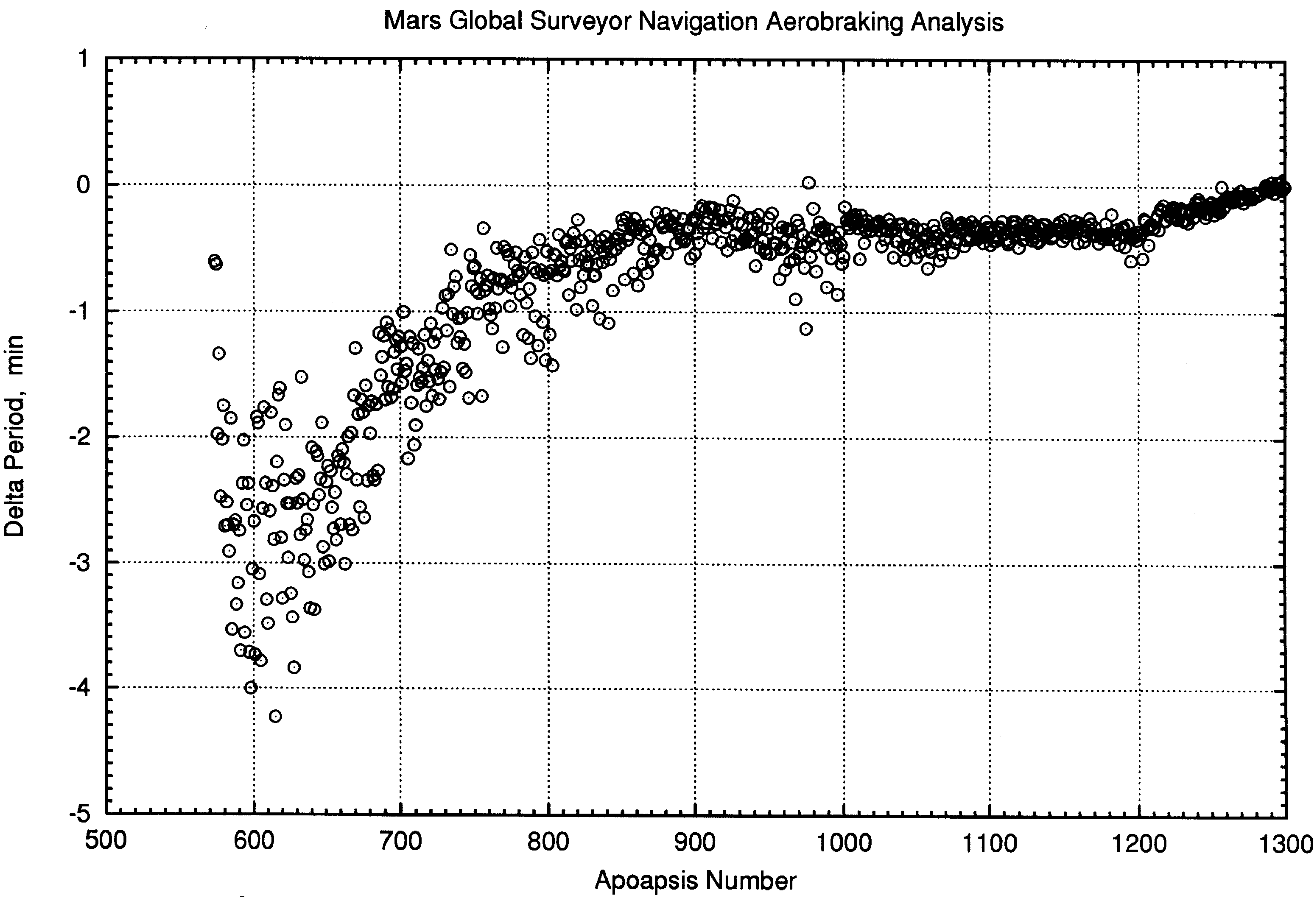

Figure 3

Prediction: P1289,...

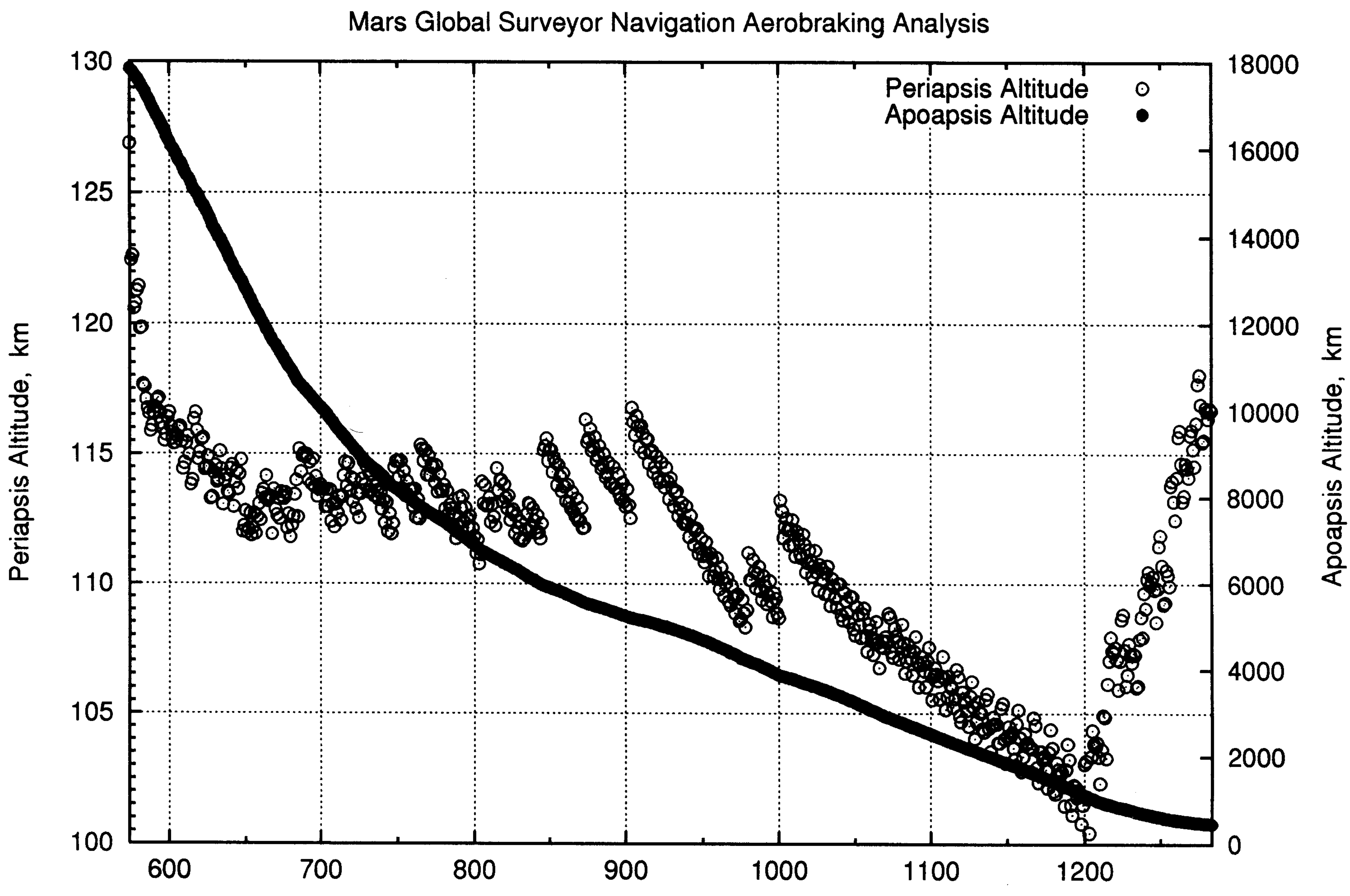

Figure 4

Prediction: P1289,...

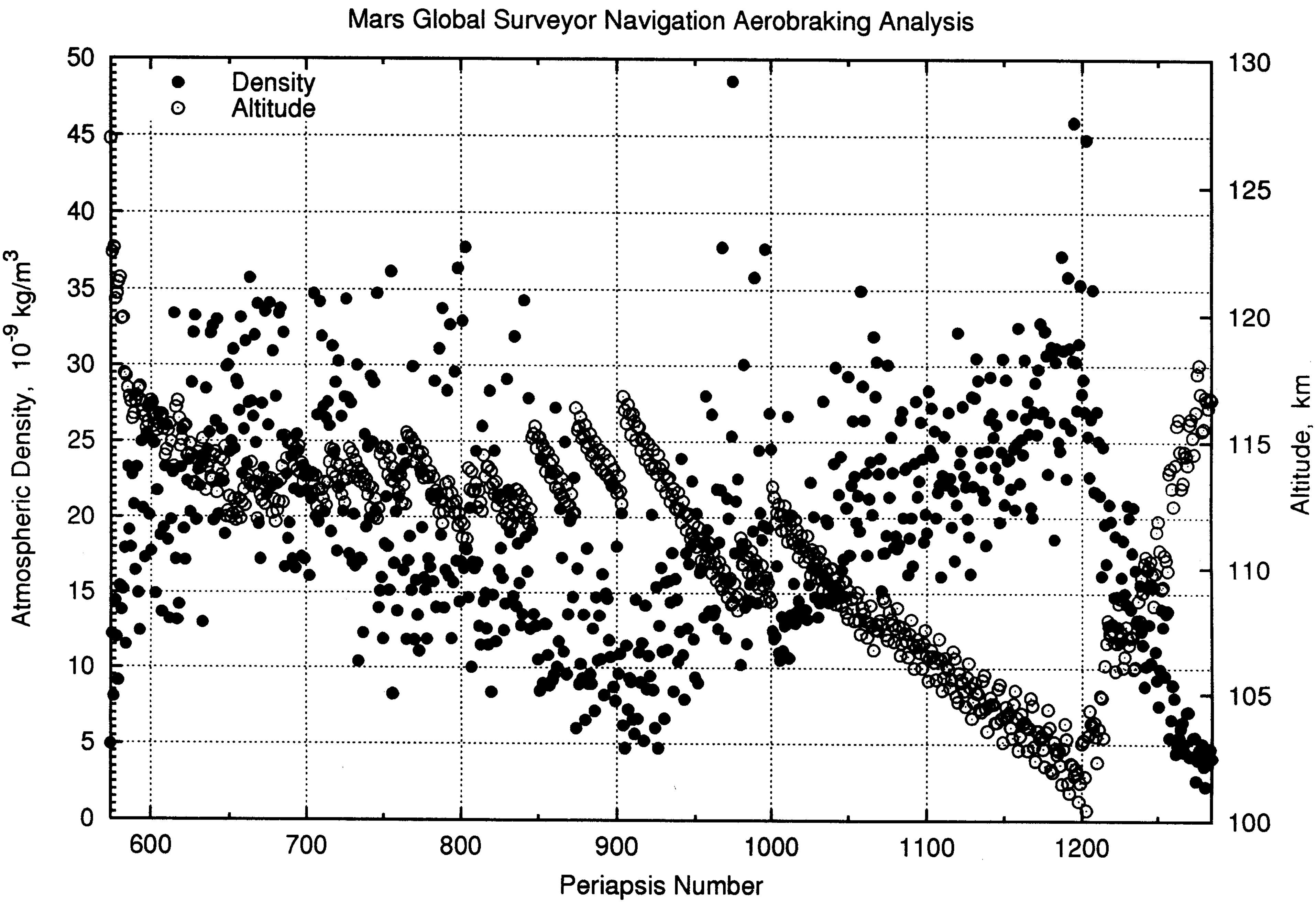

Figure 5

Prediction: P1289,...